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CALIFORNIA ROAD METER STUDY

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JUNE, 1972

M&R NO. 655190

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STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY
RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

June, 1972

M&R No. 655190

Mr. Travis W. Smith
Maintenance Engineer

Dear Sir:

Submitted for your consideration is a report on

CALIFORNIA ROAD METER STUDY

Study made by ------------------	Concrete Section
Under direction of --------------	D. L. Spellman
Supervised by ------------------	J. H. Woodstrom
Report prepared by --------------	D. D. Howard and B. F. Neal

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

Attachment

REFERENCE: Howard, D. D. and Neal, B. F., "California Road Meter Study", State of California, Department of Public Works, Division of Highways, Materials and Research Department, March 1972.

ABSTRACT: The Impact-O-Graph and the Road Meter were evaluated to determine the best instrument to use as an objective means of establishing work priorities for maintenance of roadways. Later an analog recorder was added to the Road Meter.

The study included comparison runs with the CHLOE Profilometer, runs at different speeds, with different drivers, and varying weight and tire pressures. Comparison runs were also made with the Road Meter Recorder and the California Profilograph.

KEY WORDS: Road Meter, Profilometers, riding quality, pavement evaluation.

ACKNOWLEDGMENT

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CALIFORNIA ROAD METER STUDY

INTRODUCTION

The problem of rating pavement performance or distress by objective means is not new. Many states[1-5], along with California, have developed equipment to perform this duty. However, almost all of these systems require the use of highly sophisticated equipment.

Several states[6-13] are using or are evaluating systems that can be used by field personnel without the need for costly equipment or a technical background to rate pavement condition. Most of these systems use devices fitted into ordinary passenger cars, and give an indication of pavement roughness while the car is being driven at normal highway speeds. This approach to the problem seemed best suited to California's needs.

This study was originally initiated to determine the feasibility of using the Impact-O-Graph as an objective means of establishing work priorities for corrective maintenance of certain roadway portions. The scope of the study was later broadened to include testing of the PCA Road Meter and the development and testing of a strip-chart recorder to work in conjunction with the Road meter.

CONCLUSIONS

The Impact-O-Graph is highly responsive to the vehicle in which it is used, but requires too much operator judgment in evaluating the tapes. Test runs made with the device in different autos and with different drivers were not correlative. This precluded its use in a Statewide program.

The PCA Road Meter and its subsequent modification is capable of reasonably good repeatability, correlation between cars and drivers, and to a large degree there is correlation with other roughness measuring devices.

The strip-chart recorder, while not fully evaluated, appears to be a valuable adjunct to the Road Meter. Its graphic display of bumps occurring at bridge approaches or other specific locations together with numerical data should be of help in setting maintenance priorities for repair.

RECOMMENDATIONS

1. The Road Meter should be the principal instrument used in a Statewide survey of pavement serviceability. The strip-chart recorder should be used in evaluating bridge approaches and isolated rough areas. Both instruments should be calibrated periodically.

2. Until reliable correlation factors are developed for speeds other than 50 MPH, the Road Meter should be operated at 50 MPH during testing.

3. There should be two persons in the front seat during testing. This is primarily for safety, but also tends to speed up operations, particularly if a two channel recorder is used.

4. No runs should be made when the wind velocity exceeds 15 MPH or when it is gusty.

5. Close attention should be paid to the condition of the car's tires and suspension. Shock absorbers should be replaced every 20,000 miles or less, and tires should be in balance at all times.

DISCUSSION

Impact-O-Graph

The Impact-O-Graph is a mechanical recording accelerometer which can record shock and impact from any direction as a continuous trace on a pressure sensitive tape. The entire unit is contained in a one-foot square, by four-inch deep carrying case. It is powered by a 12-volt motor connected to the cigarette lighter socket of the test vehicle. The recording tape moves at a constant rate, independent of the forward speed of the automobile. In operation, the instrument is placed firmly on the floor of the automobile and is turned on when approaching any suspected bump. It is left on until the area in question is passed. To insure uniformity, all readings are taken at the same vehicle speed. By using the same driver and car, the information gained can be used to give a relative indication of driver comfort.

Since an Impact-O-Graph was already in use by District 07 Maintenance, arrangements were made to observe the unit in actual practice, and later to borrow it for testing in the Sacramento area by Materials and Research Personnel.

A limited test program was set up in which readings were taken of several sections of roadway exhibiting varying degrees of roughness. Also, in order to determine the vehicle variables involved, duplicate runs were made using two different models of automobiles.

Through visual observation of the unit in operation, and analysis of some of the tapes, a few pertinent factors concerning its use became evident:

1. Due to the sensitivity of the unit being evaluated, its relatively slow frequency response did not accurately record high frequency, short duration jerks and bumps.

2. The vehicle suspension, tire pressure, speed, and driver all have a marked effect on the reproducibility of the data.

3. A fair amount of operator judgment is required to interpret the tapes and establish maintenance priorities.

In an effort to overcome some of these difficulties, a new Impact-O-Graph with greater sensitivity was obtained. Although the roughness, as shown on the graph, was more readily discernible, the other problems were still evident. Therefore, it was concluded that this instrument could be of only limited value in the projected program.

PCA Road Meter

The Road Meter was developed by M. P. Brokaw of the Portland Cement Association, to provide a means of evaluating pavement riding quality at vehicle speeds consistent with traffic conditions. The Road Meter is an electro-mechanical device, installed in a passenger automobile, which records the number and magnitude of rear axle movements with respect to the vehicle chassis, and displays them in numerical form. It is composed of two basic units: one is the console, in the front compartment of the car, containing the counters and power switches; the other is a box in the rear of the car, containing the switch plate, contact rollers, and connection to the differential housing.

A Road Meter was made available by loan from the Portland Cement Association, and was installed in a laboratory car for testing. A number of runs were made to measure its repeatability and to establish a correlation with the CHLOE Profilometer. The repeatability of the instrument was assured (Table 1) and a reasonable correlation with CHLOE was worked out (Figure 1). Runs were made on sites scattered throughout the State, to gain experience with the unit and to check subjective observations with Road Meter results.

The original model of the Road Meter was considered to have several disadvantages. A cable was attached to the top center of the differential housing, then run through the trunk compartment to the package shelf behind the rear seat. A box mounted there contained numerous pulleys, springs, and cables, as well as the switch plate and roller contacts (Figure 2). Due to close quarters under the rear window, inspection and maintenance of the moving parts was difficult. Connection to the switch plate for operation of the meter could only be accomplished by stopping the car and getting into the back seat. Nulling (setting the reference plane to zero) was done, with the car at rest, from the front seat by reaching into the rear with an extension rod and adjusting a vernier control. It is considered desirable to improve some of these features without changing the basic concept.

Cox Road Meter

Consultation and pooling of ideas led to the construction of a modified Road Meter by James Cox and Sons. In this model, the translator assembly (switchplate and contact rollers) is mounted in the trunk compartment in a vertical position (Figure 3). All pulleys, cables, and springs were eliminated. The two roller microswitches are connected by a rod directly to the differential housing. When actuated, the rollers impinge on the printed circuitboard (divided into 1/8 inch segments) which in turn transmits signals to the counters mounted in the console in the front compartment of the vehicle (Figure 4).

To operate, the power switch is turned on, activating a vacuum device to bring the rollers in contact with the circuitboard. To set the reference plane, or zero balance, the circuitboard is moved by means of a small DC motor so that the center segment of the circuitboard is in contact with the rollers. Indicator lights on the console show the position of the board at all times. When the null position is established, the switch controlling the counters is turned on and the meter is in operation. The entire operation can be carried on without stopping the car.

Six of these new type meters were installed in cars being used by Maintenance Department survey teams, and one in a laboratory car. All cars were 1969 Ford Fairlanes with standard suspension. A series of test runs were then made to determine the repeatability of the various units and to set up a common factor between the cars.

Further test were then made using the laboratory car to determine which factors significantly affect Road Meter results. The first series of tests included the following variables:

1. Added weight in the car, including amount of gasoline

2. Tire pressure above and below normal

3. Different drivers and operators

4. Various speeds

A statistical analysis was made of the results obtained (Tables 2 and 3), and it was found that adding weight in the trunk of the car within reasonable limits, varying the amount of gasoline in the tank, using a tire pressure within $\pm$ 4 lbs. of the normal of 26 lbs., and interchanging drivers and operators made no significant changes in the results. However, runs at speeds other than 50 MPH were highly significant. As it is sometimes desirable to make runs at speeds other than 50 MPH because of traffic conditions or geometrics, more tests were made in an attempt to obtain a factor for this use. Runs made at some speeds did show a fair correlation with those made at 50 MPH, but more tests will have to be made before reliability can be assured (Figures 5, 6, 7, and 8). (Additional information will be supplied on this aspect as it becomes available.)

A limited number of tests were made to determine the effect of variations in air temperature on test results. Test runs on a PCC pavement showed a decrease in counts with a rise in temperature, while those made on an AC pavement showed the opposite.

Previous work with the California Profilograph has shown that a great number of PCC pavements tend to become smoother in the warm part of the day, but no data is available on AC pavements.

The condition and type of shock absorbers on the test vehicle can have a significant effect on the test results. The original equipment shock absorbers on the Laboratory car deteriorated rapidly causing wide variations in the number of counts on repeat runs. In an effort to remedy this situation, heavy duty shock absorbers (load leveler type for the rear) were installed. This improved the repeatability on rough roads, but not on smooth ones. It was also felt that many of the smaller bumps were being filtered out. The car was then equipped with standard duty shocks of a better quality than the original set. This brought about a marked improvement in the test results on all types of roads.

Strip-chart Recorder

Since an instrument was needed to objectively measure the roughness of bridge approaches and short lengths of pavements, it was decided that the Road Meter would be capable of doing this if a strip-chart recorder could be attached. Such a recorder was designed and built by James Cox and Sons, providing an analog printout of Road Meter Measurements as compared to the digital form of the original equipment.

The recorder, which is mounted over the rear seat of the test vehicle, has its pen drive mechanism fastened directly to the translator assembly of the Road Meter and shows graphically the same road-car deviations as depicted digitally on the Road Meter console. The recorder chart drive is driven by servomotors powered by the speedometer drive of the car. The chart speed can be preset by means of a potentiometer in the system. Starting of the chart drive and operations of the pen are controlled from the Road Meter console. Because of the greater magnitude of excursions, the charts are much easier to compare than those made with the Impact-O-Graph. Figure 9 illustrates a typical condition.

Upon completion of calibration runs, the Laboratory car and recorder were loaned to District 07 maintenance for trials in the Los Angeles area. A number of bridge approaches were tested to acquaint personnel with the equipment, and upon return of the car to Sacramento, a program of charting all PCC bridge approaches in Northern California was begun. To date over 3100 approaches have been tested and the charts identified and indexed. Evaluation of these charts is being done under a separate Federally sponsored research project.

A second recorder has been completed and installed in another car for use in Southern California. Graphs obtained with this recorder are nearly identical to those obtained by the recorder in the Laboratory car.

A few runs were made in an attempt to correlate this equipment with the California Profilograph. The overall graph as drawn by the Road Meter recorder, is similar in appearance to that drawn by the Profilograph, but the magnitude of the bumps is different. At slow speeds (below 20 MPH), the Road Meter recorder clearly shows the faulting at joints, but unlike on profilograms, is not directly measurable (Figure 10).

FURTHER NEEDED RESEARCH

1. Whenever a change in vehicle is necessary, the new vehicle should be equipped with a Road Meter and comparisons made with the old equipment.

2. A more precise method of calibrating the Road Meter should be worked out. The present method of a number of runs over a test track is time consuming and at the mercy of the weather. Work should be directed toward building a ride simulator to check the car's reaction to a programmed series of bumps.

3. More work should be done toward establishing a correlation with the California Profilograph and a means of obtaining measurable faulting data. A good correlation could mean replacing the Profilograph in use on roads open to high-speed traffic.

4. A better correlation between various speeds should be established. All work done so far has been with one car and it is not known if these figures are valid for all the Road Meter cars.

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Table 1

(Repeatability tests at different speeds.)

PCC Pavement - Fair Condition

Speed	No. of Tests	Mean Σ Counts per Mile	Std. Dev.	C. V. %
30	15	677	42.1	6.2
40	15	736	25.5	3.5
50	26	1026	92.1	9.0
60	15	1515	95.6	6.3
		PCC Pavement - Faulted		
30	15	1956	115.0	5.9
40	15	2143	126.5	5.9
50	29	2040	114.6	5.6
60	15	3415	149.1	4.4

Table 2

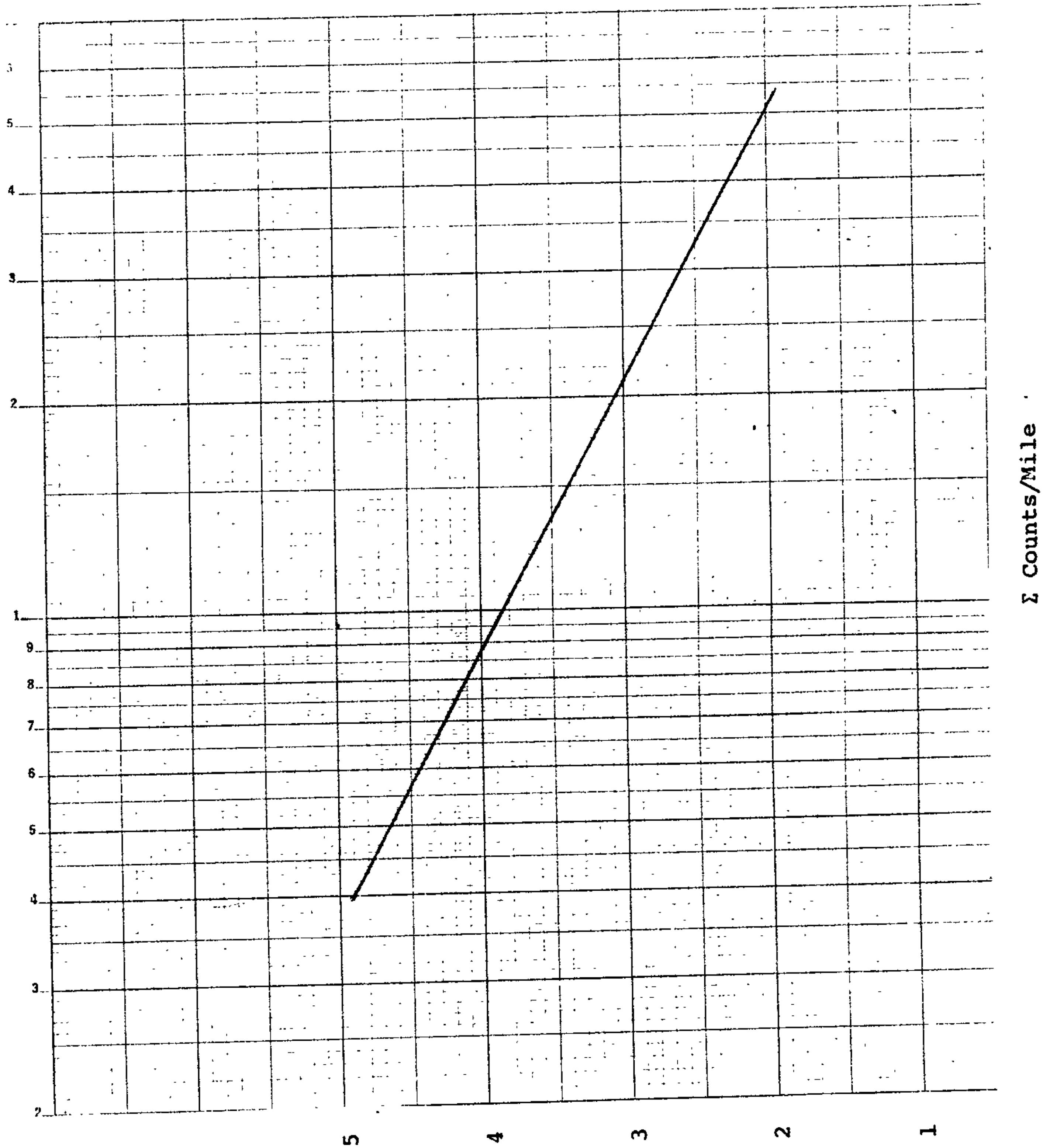
Analysis of Variance for Speed, Tire Pressure, and Added Weight

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Squares	"F" Ratio	"F" for Significance level of 5%	1%
Speed	2,845,591	2	1,422,795	107.2	19.00	99.00
Tire Pressure	47,185	2	23,592	1.78	19.00	99.00
Weight in Trunk	16,141	2	8,070	0.61	19.00	99.00
Residual Error	26,561	2	13,280			

Table 3

Analysis of Variance for Speed, Gas Tank Quantity, and Different Operators

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Squares	"F" Ratio	"F" for Significance level of 5%	"F" for Significance level of 1%
Speed	1,635,300	3	545,100	206.4	4.76	9.78
Gas Tank Quantity	25,171	3	8,390.3	3.18	4.76	9.78
Operator	15,714	3	5,238	1.98	4.76	9.78
Residual Error	15,847	6	2,641.1			



CHLOE PSI - Portion attributable to slope variance

Figure 1

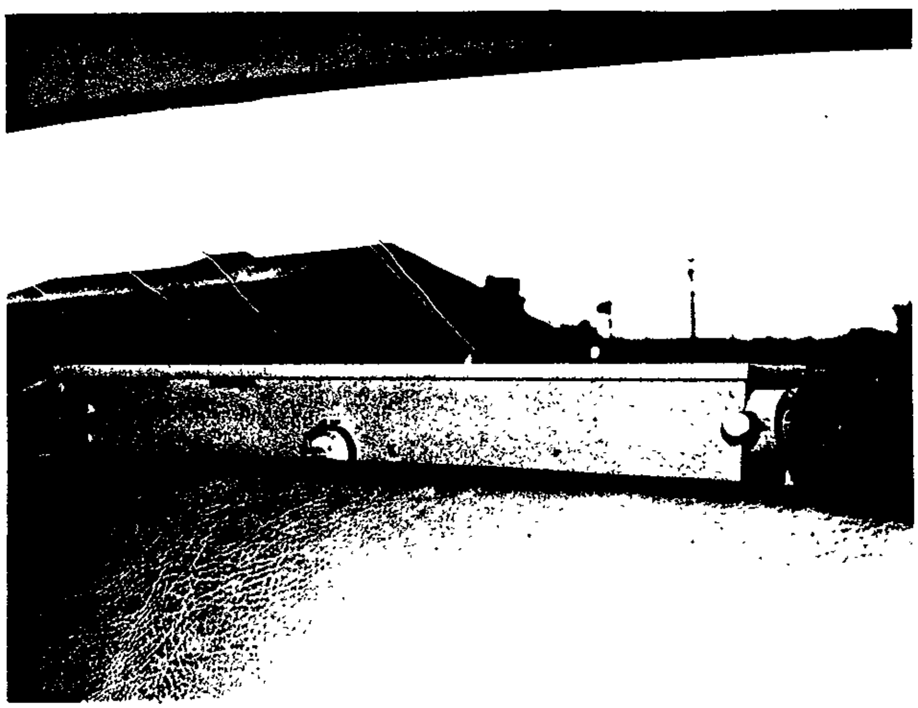


Figure 2

Road Meter Assembly
(Brokaw Type)

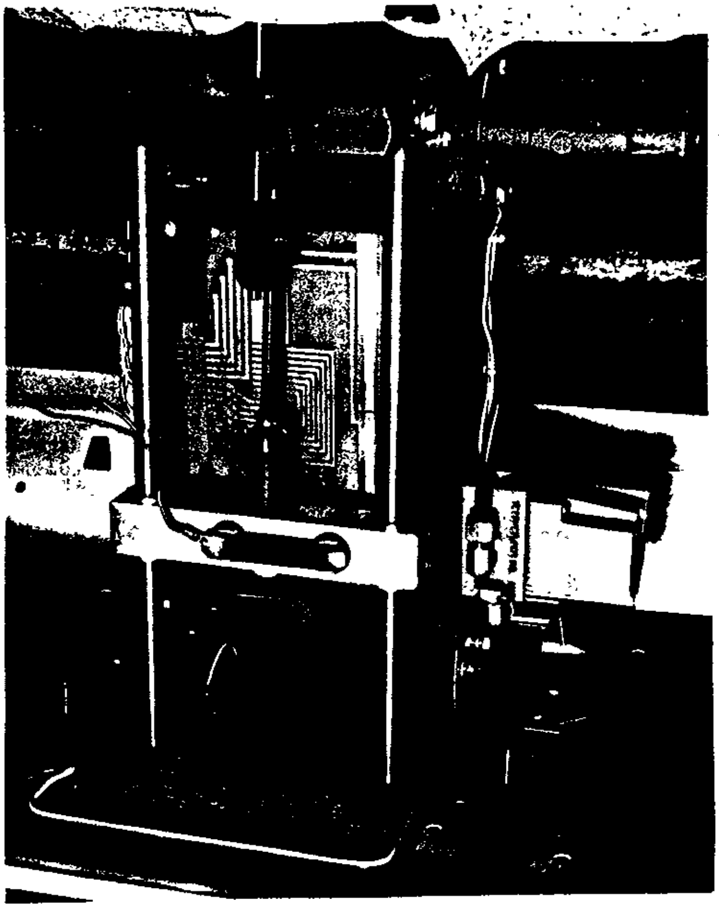


Figure 3

Road Meter Translator Assembly
(Cox Type)

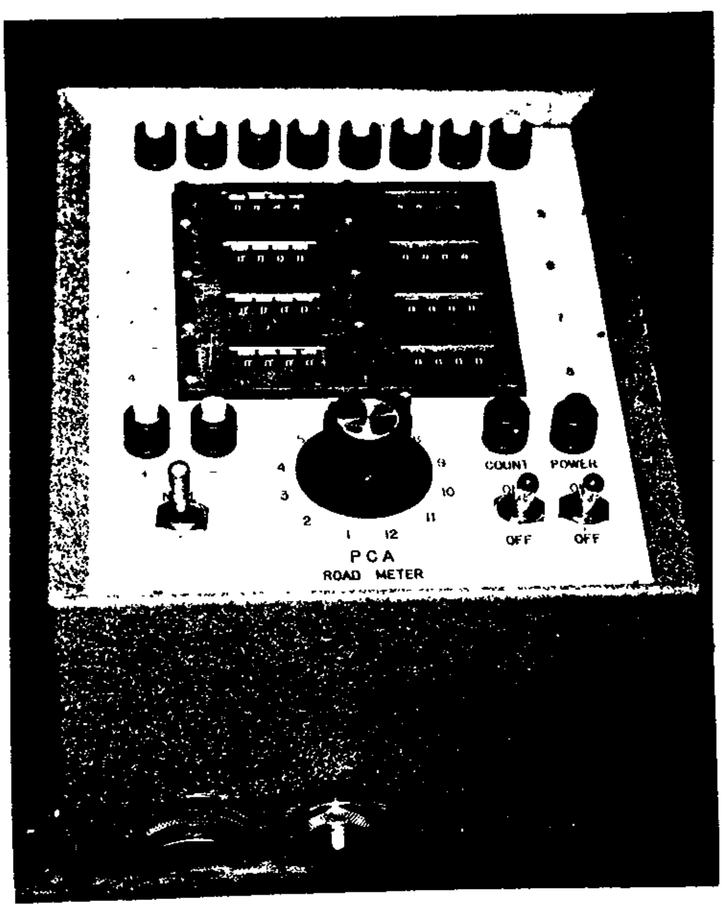


Figure 4

Road Meter Console
(Cox Type)

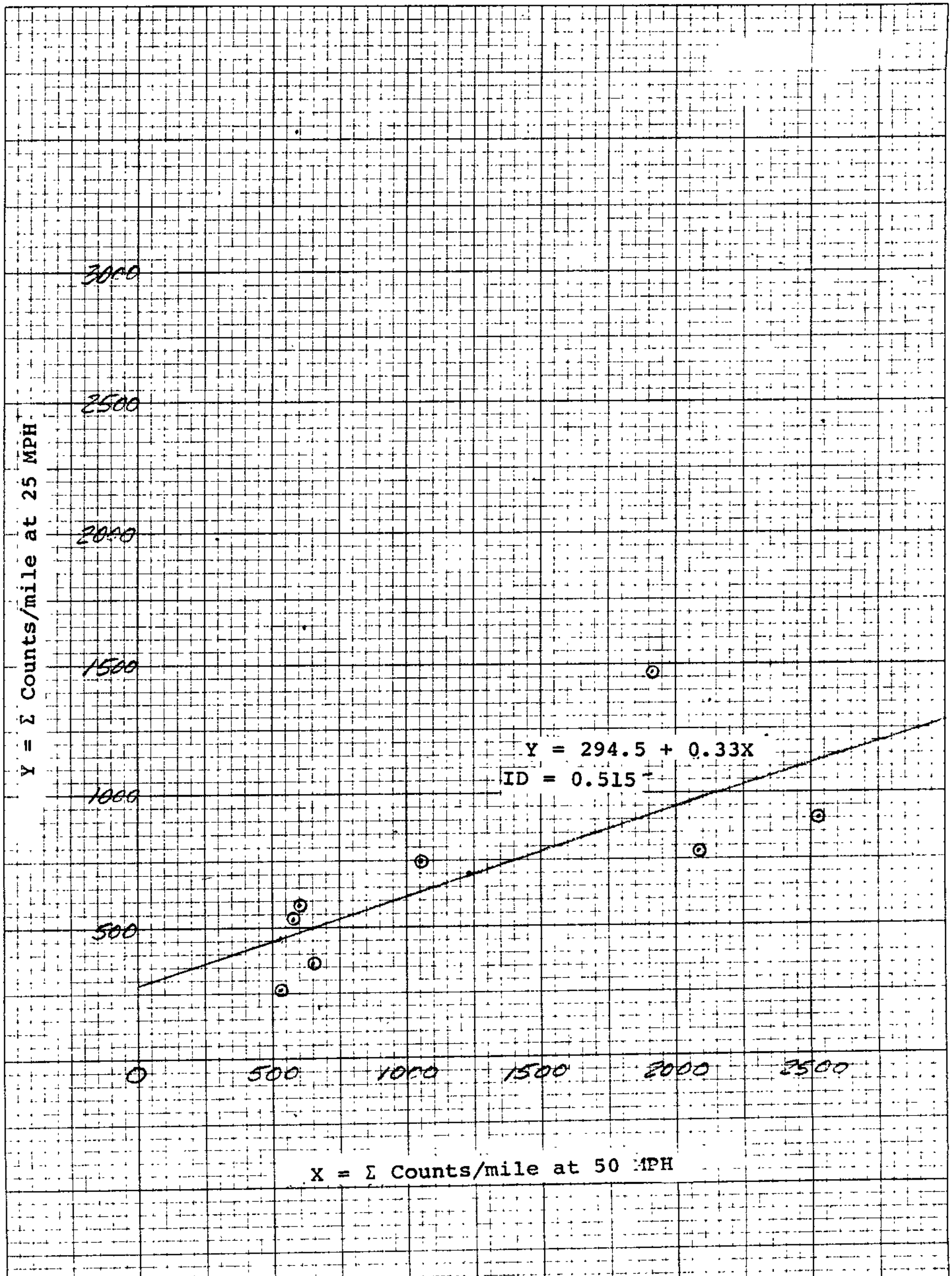

3000
2500
2000
1500
1000
500
0
500
1000
1500
2000
2500
Y = Σ Counts/mile at 25 MPH
Y = 294.5 + 0.33X
ID = 0.515
X = Σ Counts/mile at 50 MPH

Figure 5

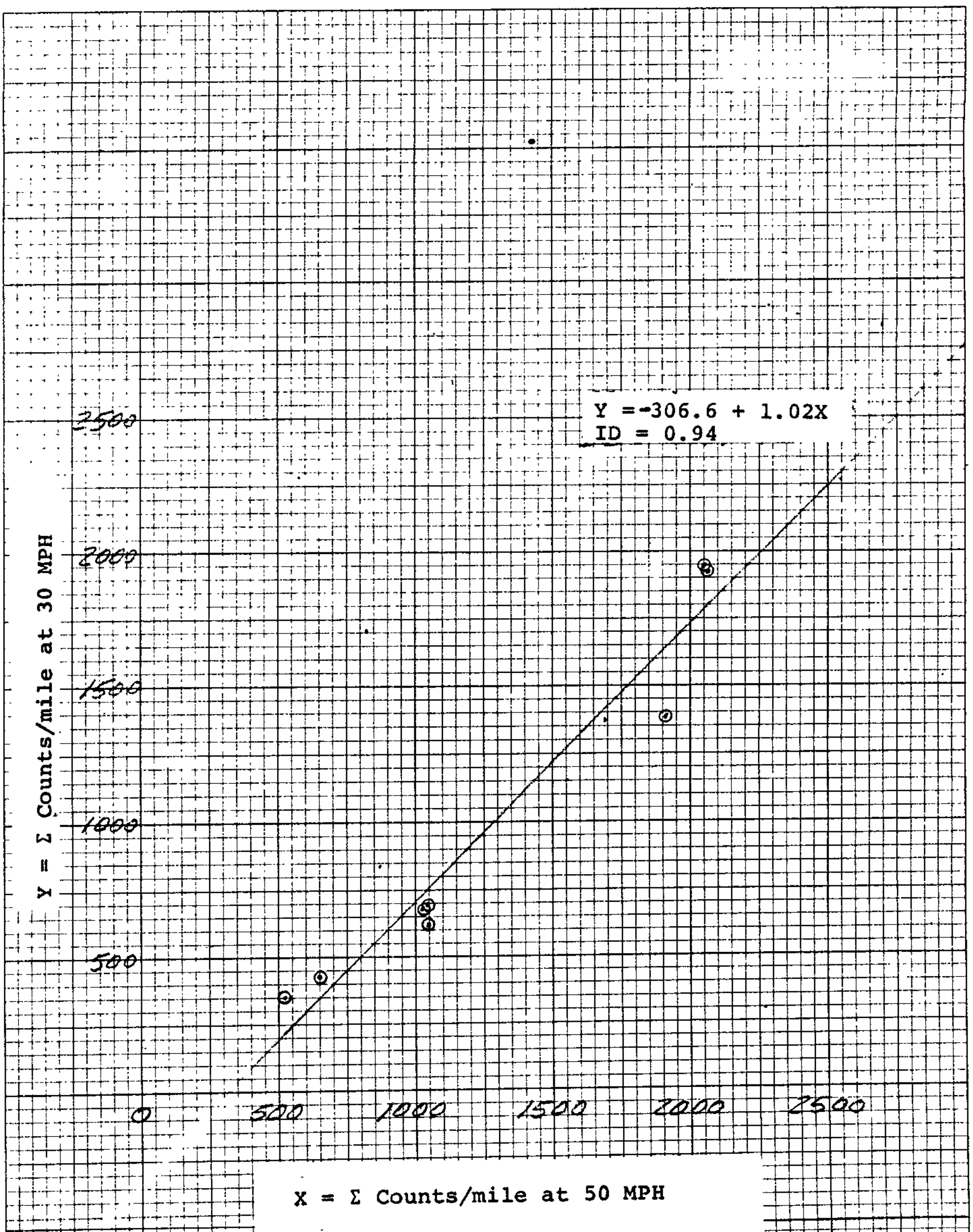

Y = -306.6 + 1.02X
ID = 0.94
Y = Σ Counts/mile at 30 MPH
2500
2000
1500
1000
500
0
500
1000
1500
2000
2500
X = Σ Counts/mile at 50 MPH

Figure 6

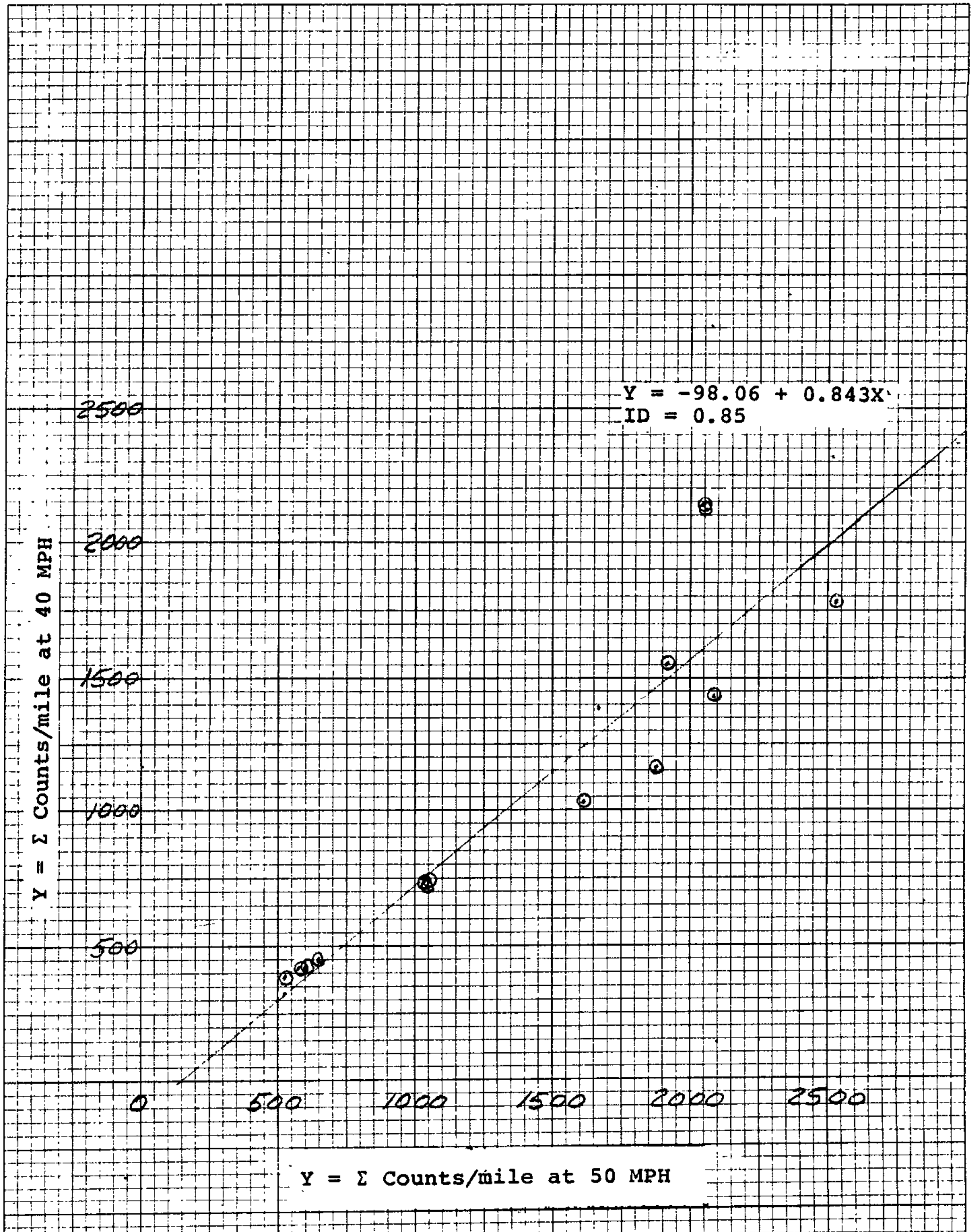
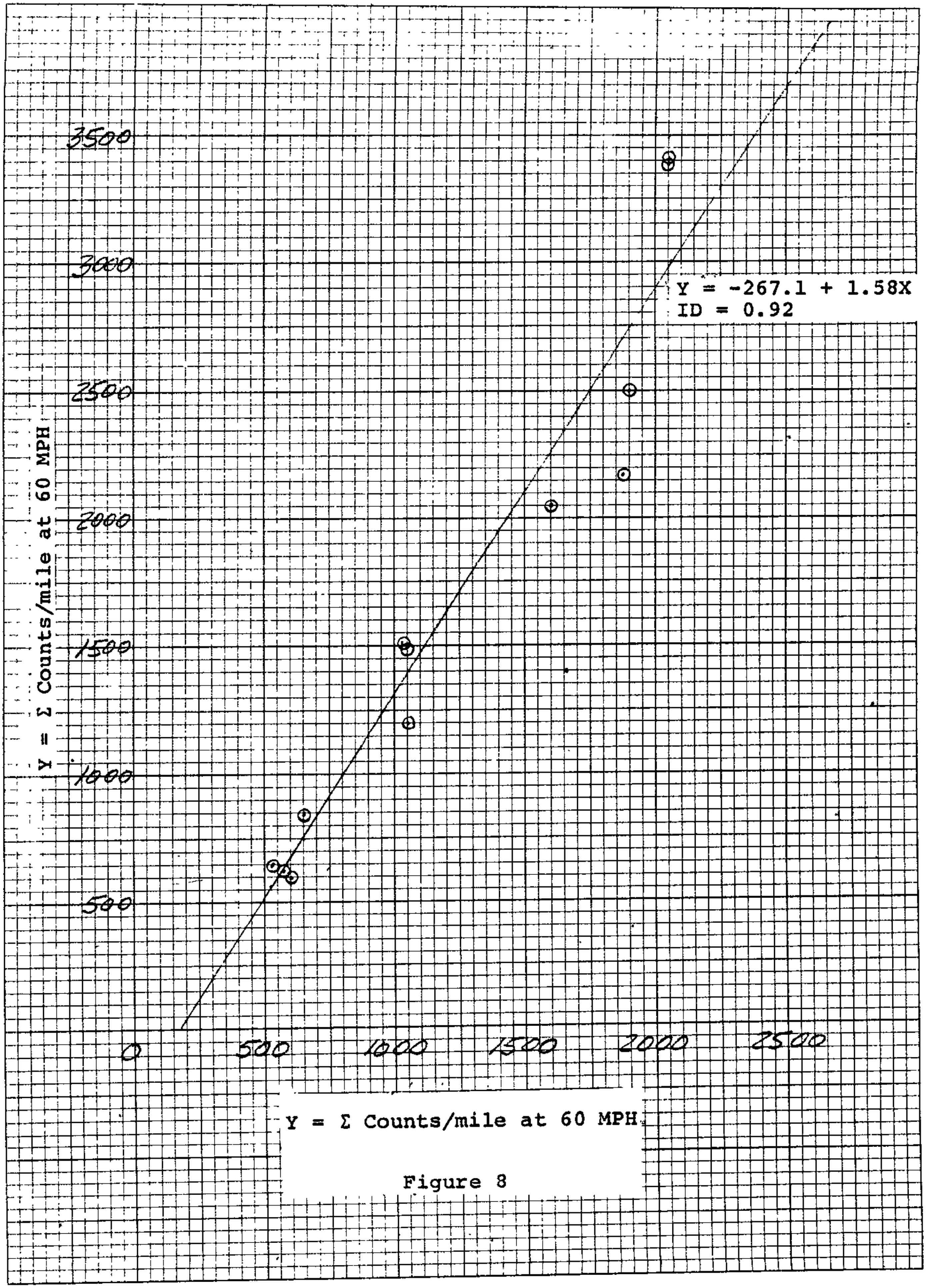
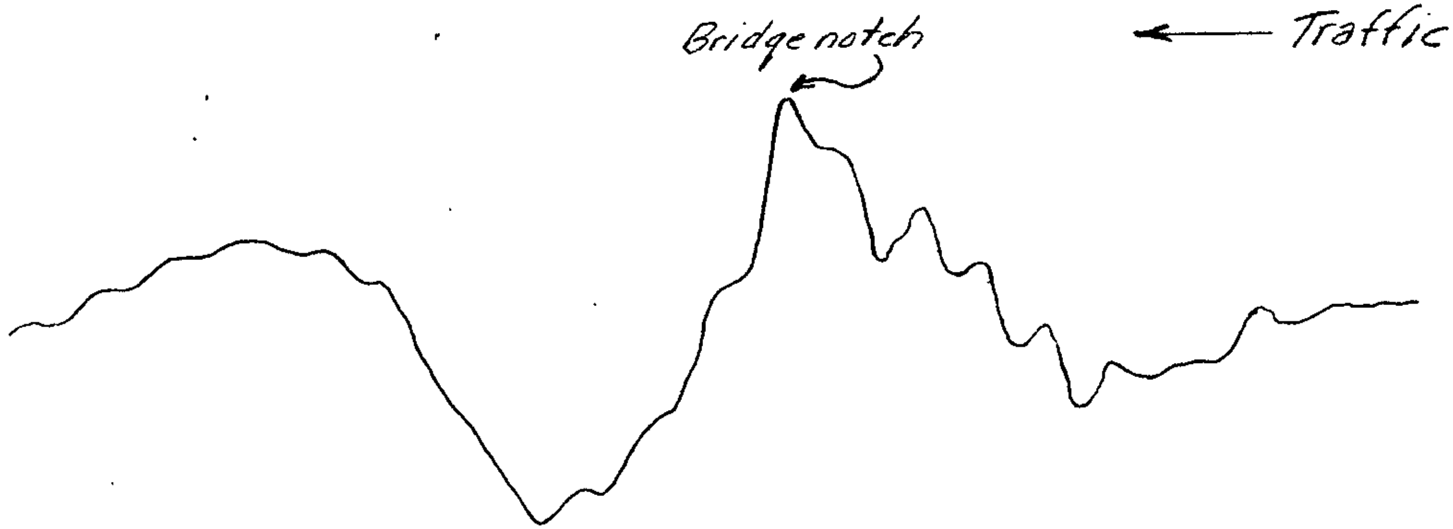

Y = -98.06 + 0.843X
ID = 0.85
Y = Σ Counts/mile at 40 MPH
2500
2000
1500
1000
500
0
500
1000
1500
2000
2500
Y = Σ Counts/mile at 50 MPH

Figure 7

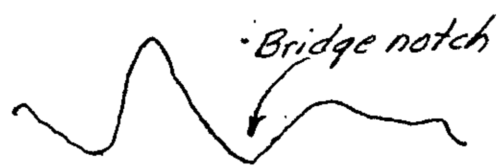


Y = Σ Counts/mile at 60 MPH
3500
3000
2500
2000
1500
1000
500
0
500
1000
1500
2000
2500
Y = -267.1 + 1.58X
ID = 0.92
Y = Σ Counts/mile at 60 MPH

Figure 8



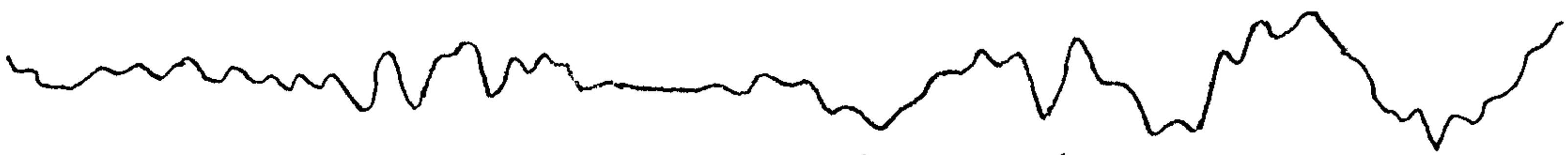
Road Meter Recorder



Impact-O-Graph

Comparison Traces - Bridge No. 24-243L

10 SJ 5 - Profilograph



10 SJ5 - Road Meter Recorder
@ 50 MPH

Typical Faulted Pavement - Profilograph

Typical Fauted Pavement - Road Meter Recorder
@ 20 MPH